

Low-Cost Multi-Spectral Camera Platform for In-Flight Near Real-Time Vegetation Index Computation and Delivery

Lucas Diogo de Mendonça^{1,2}
Cesar Giovanni Chaves Arroyave¹
Eduardo Rodrigues de Lima¹
Luiz Eduardo Vicente³

¹ Instituto de Pesquisas Eldorado
Av. Alan Turing, 275 – 13083-898 – Campinas – SP, Brasil
{lucas.mendonca, cesar.arroyave, eduardo.lima}@eldorado.org.br

² Universidade Estadual de Campinas – UNICAMP
Cidade Universitária Zeferino Vaz – 13083-970 – Campinas - SP, Brasil

³ Empresa Brasileira de Pesquisa Agropecuária – Embrapa Meio Ambiente
Rodovia SP 340, KM 127,5 – 13820-000 – Jaguariúna - SP, Brasil

Abstract. Agricultural optimization and increased productivity is always a growing concern, due to the increasing population. Crops susceptible to a wide variety of hindering conditions, need to be carefully observed and managed to guarantee maximum production. Many diseases, weather changes, soil variances and other influencing factors are only visible after the plant has reached a deplorable state and its neighbors closely trailing behind. Ongoing research is enhancing an observation model that can better prevent such factors, but many still present a variety of limiting factors that are still being studied. Vegetation indices is a long dated studied concept that has proven to be able to show plant response to stress before visible signs are present. To take advantage of this we propose a multi-spectral camera, aimed at mass use, to provide the needed observation with top of the line, reliable results. The built prototype was put through two different tests, both showing it capable of displaying plant health. The fine control test showed the camera capable of displaying difference in plant health after only two days of stress. The results were reached with out the use of expensive lenses/filters, and provide easy to interpret results. All while being able to send data to a nearby portable device.

Keywords: remote sensing, image processing, high resolution sensoriamento remoto, processamento de imagens, alta resolução

1. Introduction

The use of remote sensing data has been for years a powerful tool used by government and agencies on observing and managing vegetation (MORAN; INOUE; BARNES, 1997), forestry (COPPIN; BAUER, 1996), land use (VOGELMANN et al., 2001), planning (JAT; GARG; KHARE, 2008) etc. A major field of research has been to use remote sensing data to identify characteristics of agriculture (BASTIAANSEN; MOLDEN; MAKIN, 2000) (GITELSON, 2016) to support management of plant diseases (RAJI et al., 2016), infestation (NANSEN; ELLIOTT, 2016), water stress (TILLING et al., 2007), etc. Such studies lead also to important management statistics such as yield estimates (SHANAHAN et al., 2001). Observation of agricultural data in specific has seen many different applications made that link specific characteristics to that of sensed data.

Being able to identify the overall health of plantations and possible problems, interest more than just big entities. Such information is a powerful tool to all who depend on plantations to earn their yield. Currently big data, complexity of data, high expertise, and an overall lack of information make the results of such remote sensing data a high barrier to overcome for

most. There has been an increase in public interest in the use of Unmanned Aerial Vehicles (UAVs)(WEISSBACH et al., 2016)(BRIEF, 2011), these are seen as a way to simplify a vast variety of different tasks and drive down costs. Undoubtedly prices have seen a shift, and a market that was mostly dominated by complex and expensive UAVs, now has easily accessible UAVs with simplified controls. The popularity of such equipment unfortunately has not been so closely followed by multi-spectral cameras.

The equipment, capable of providing instantaneous results to help field owners on making decisions and plans. These cameras are usually equipped with multiple sensors, variety of very specific and expensive filters. The equipment also needs training to set up and use, good results are hidden behind lots of complex processing software and not so simple information. Acquiring data also means setting up complex flight plans, acquisition locations, coverage areas, multiple runs due to the most varied complications. The entire process being very time consuming and complex for someone wanting a simple and fast answer.

Due to all these observations and restrictions, we propose this project. A cheap multi-spectral camera, projected at simple UAVs, to deliver simple identifiable results. Inspired on modern cameras, that has high quality sensors, high durability, and small sizes to be also brought to the multi-spectral cameras. The possibility of identifying reliable results with out the need for expensive and sensitive lens, composed of widely available equipment off the shelf. All this while delivered in-flight results to common devices.

2. Proposed Low-Cost Multi-Spectral Camera Platform

In order to create a low-cost multi-spectral camera, common inexpensive good-quality elements where gather. Such elements include two units of a same commercial camera model, a Single Board Computer (SBC) and a USB-WiFi dongle. As depicted in Figure 1, the remote-sensing setup is divided in two parts: 1) the *in-the-air* section encompasses the proposed camera and a battery pack; 2) in the *on-land* side, a notebook can switch between two modes of operation: 1) periodical-shooting and 2) shoot, process and send.

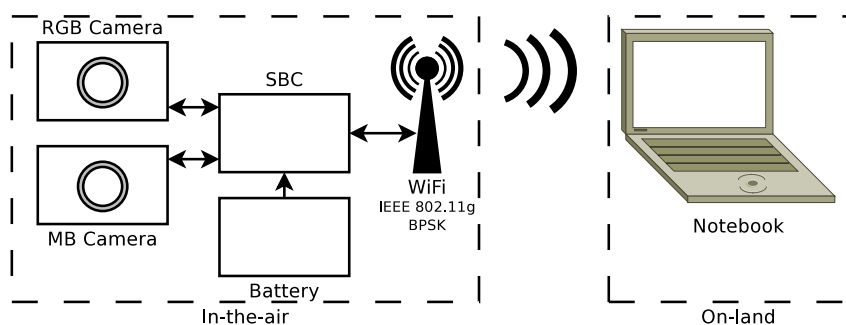


Figure 1: Remote-sensing setup.

The current set-up was conceived as a four-band camera; considering Red, Green, Blue and Infrared bands. The four bands are achieved by a combination of two identical RGB cameras (i.e. containing identical hardware and firmware configurations). Hardware configurations are usually identical within the same model number of a product, however, many different firmware versions may be found for a single model number.

The camera model was chosen according to the exact spectral response of its CMOS sensor, reported by the manufacturer in the data sheet. Figure 2 shows the spectral response curve of the selected camera model, proving its capability to sense Near-Infrared data.

Both cameras were updated to the most-current available firmware version and equally configured using their options menu. Such configurations correspond to: 1) disabling the auto

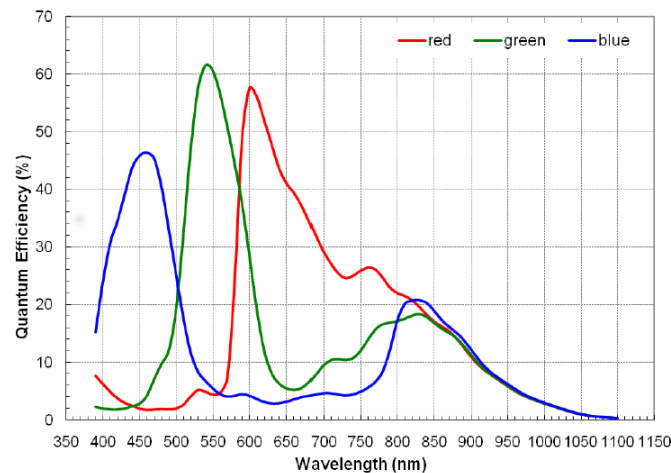


Figure 2: Manufacturer's reported CMOS sensor responses.

white balance, assigning a middle temperature value; 2) setting the ISO sensitivity to the lowest available value to maximize image sharpness; and 3) completely reduce the shutter speed value to reduce possible motion blur. Moreover, the auto focus function was left unfixed for this first prototype. These settings are important to guarantee the energy values being captured. Although these settings were found to be the most reliable configuration for outdoor capture during bright days, more sensitive results can be achieved configuring the camera for specific test conditions.

Up to this point both cameras are technically identical, containing a sensor capable of sensing the entire band, but restrained by an optical filter that blocks radiation above the red band. Such filter is removed from one of the cameras, which will from now on is labeled as Mixed-Band (MB) camera, since its RGB bands are now mixed with the bands that were filtered. The other camera is now labeled as RGB camera. The cut-off band of the filter was not measured, however, it does not affect the correction process.

Furthermore, some cables were welded to the cameras to enable a SBC to control them. Such control includes: 1) turning them on and off; 2) setting them to picture mode; and 3) taking the picture. It is essential that both cameras take the pictures at the same time for them to correspond to a same area and subsequently for being processed together. Additionally, the SBC processes the pictures using Open CV and, by using a USB-WiFi dongle that is configured as an access point in order to be accessible by the on-land notebook.

Both cameras, the SBC and the USB-WiFi dongle fit a standard 56 x 85 x 124 mm Patola box, resulting in the low-cost multi-spectral camera prototype depicted in Figure 3. This prototype, together with a battery pack, can be attached to an UAV to carry out remote readings.

3. In-Flight Near Real-Time Vegetation Index Computation and Delivery

Once the SBC receives a picture request from the on-land computer, it executes the procedure presented in Figure 4.

First, the SBC commands both cameras to take a picture at the same time, hence the accuracy of vegetation index calculations depends on the matching possibility of the two pictures. Subsequently, both pictures are retrieved for further processing. Once both images have been received, the SBC separates each of them into three bands. From the RGB camera, the pure red, green and blue bands can be obtained: RB, GB, and BB, respectively. On the other hand, from the MB camera, non-filtered red, green and blue bands are obtained: NFRB, NFGB, and NFBB, respectively.



Figure 3: Low-cost Multi-Spectral Camera.

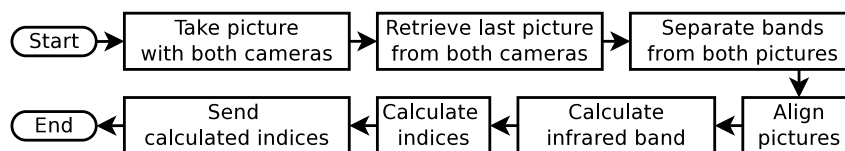


Figure 4: Picture taking procedure.

Since the six bands are capture from two different sensors, the area covered by the two pictures is not exactly the same, thus there is a separation between them. An alignment process is done in which only the common captured area is selected. A dislocation factor is calculated once, while fixing the cameras together, and used each time a picture is taken. This factor can be obtained by taking pictures of a controlled environment and calculating the distance between matching points.

In order to calculate the intended vegetation indices, the Infrared band (IB) is required. However, the equipment needed to capture such band is not commonly accessible. As said before, the chosen cameras contain a filter that blocks radiation above the red band, which is exactly the data we require. In an attempt to obtain the inverse of the filter, we subtract the RB data of the RGB camera from the NFRB of the MB camera. The resulting pseudo-infrared band will be considered from now on as IB. It is worth mentioning that the NFGB and the NFBB of the MB camera are discarded. An attempt to include this data for calculating the infrared data and to enhance the quantum efficiency balance was made, but results were inconclusive, no obvious improvement over the simple subtraction of the red bands were observed.

Now that we have IB data, the SBC calculates the following vegetation indices: Normalized difference vegetation index (NDVI) (CARLSON; RIPLEY, 1997), Renormalized difference vegetation index (RDVI)(ROUJEAN; BREON, 1995), Optimized soil adjusted vegetation index (OSAVI)(RONDEAUX; STEVEN; BARET, 1996), Enhanced vegetation index 2 (EVI2)(JIANG et al., 2008), and Modified soil-adjusted vegetation index (MSAVI)(QI et al., 1994). All the resulting indices are output as gray scale images, nevertheless, when requested, an informed Look-up-table (LUT) can be applied to the index result and output. Table 1 lists the band composition from image composites and formulation used for the chosen indices.

Table 1: Processed available outputs.

Output Data	Image	Formula	Post-Processing
Natural	[RB,GB,BB]	-	Histogram Equalization
Pseudo-IR	[IB,RB,GB]	-	Histogram Equalization
NDVI	IB,RB	$\frac{IB-RB}{IB+RB}$	LUT
RDVI	IB,RB	$\frac{IB-RB}{\sqrt{IB+RB}}$	LUT
OSAVI	IB,RB	$\frac{IB-RB}{IB+RB+0.16}(1 + 0.16)$	LUT
EVI2	IB,RB	$2.4 \frac{IB-RB}{IB+RB+1}$	LUT
MSAVI	IB,RB	$\frac{2IB+1-\sqrt{(2IB+1)^2-8(IB-RB)}}{2}$	LUT

Communication between the camera and the on-land notebook is done using WiFi, more specifically, the version compliant with the IEEE802.11g standard. IEEE802.11g presents a trade off between data rate and range (RAO; GIULIETTI, 2005)(LIMA et al., 2004), moreover, in order to grant more freedom to the UAV, the BPSK modulation with a code rate of 1/2 was chosen.

4. Performance Evaluation and Results

In order to evaluate the performance of the proposed Low-Cost Multi-Spectral Camera Platform, two test scenarios were considered: 1) a practical test using an overlooked area with different vegetation; 2) a fine control test of periodically extracted leaves.

In the first scenario, the field depicted in Figure 5(a) presented interesting characteristics such as: open soil, a grass field, trees, build up areas, and areas of transition between those areas. Although a perpendicular acquired image would have been a more controlled and realistic than the high inclination angle of the chosen scenario, no UAV was available.

For the second scenario, some healthy leaves were picked from a tree, each on a different day. All the leaves were taken from the same branch, presenting equal constant illumination conditions. The extracted leaves were stored until the end of the sample-acquiring phase. In total, four leaves were collected on October 25th, 27th, 28th and 31st. Additionally, a control leaf that was unquestionably dead was also included. Moreover, the picture in Figure 6(a) was taken on October 31st, roughly one hour after the last leaf was collected, this was the fine control test.

5. Conclusion

In summary the results can be divided by the camera's ability to generate infrared information and its derivatives as well as its communication ability. The fine control test results (Figure 6) proved the hypothesis behind the experiments, not only the vegetation indices but also the infrared composite showed visible distinction between the healthier and the earlier acquired leaves. Interpreting the practical results (Figure 5) are quite complicated since a few effects are present on such a high inclined capture. Tree tops were visibly more highlighted than other objects, grassy areas were in turn more visible than bare soil. A tricky identification was the asphalt located near the bottom of the image, its high response was contrary to expected

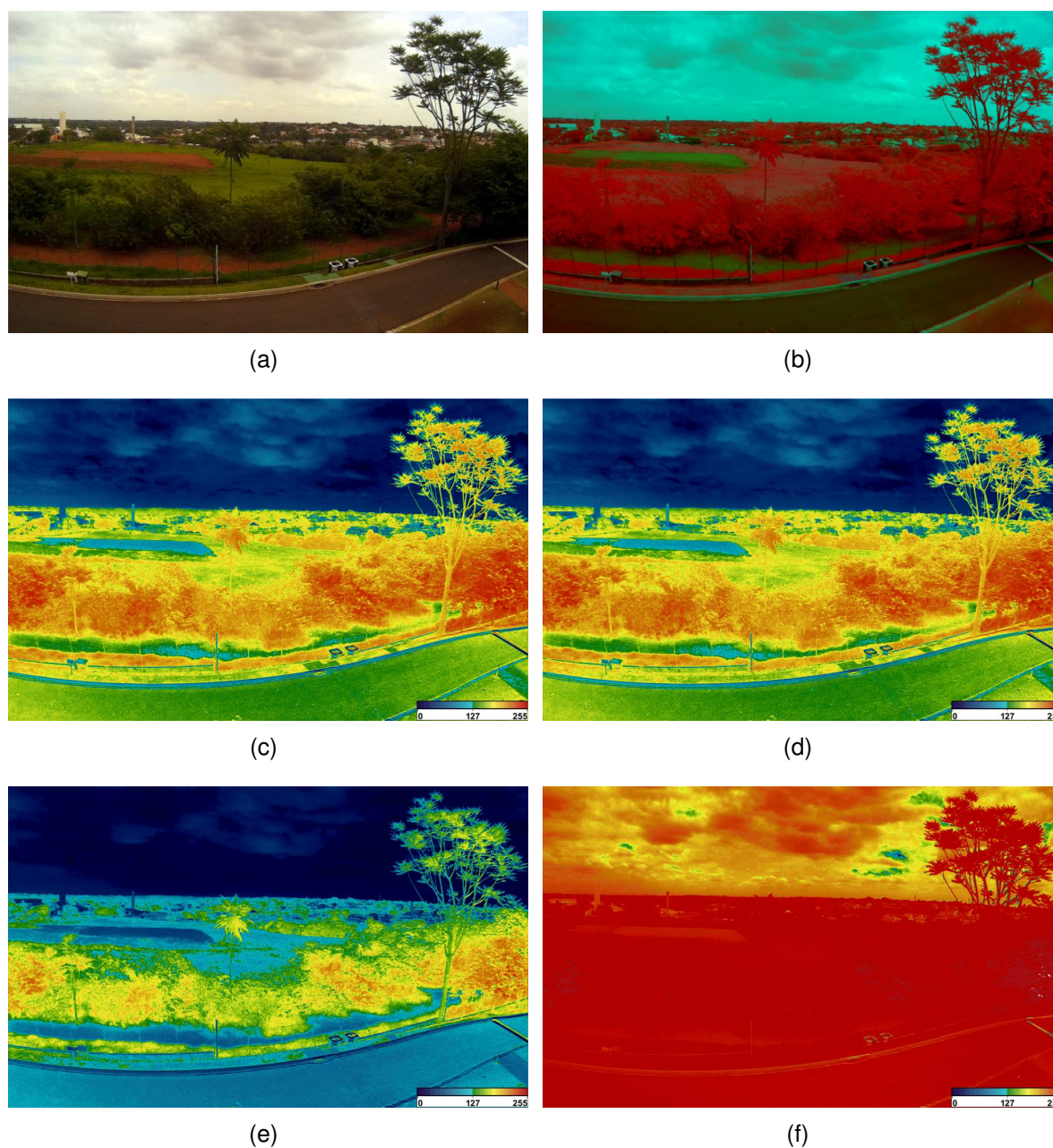


Figure 5: Overlooked area: (a) RGB; (b) IR; (c) NDVI; (d) OSAVI; (e) EVI2; (f) MSAVI

results. A reasonable explanation might be linked to the fact that excessive temperatures from it were also captured at higher wavelengths no longer blocked by the filter. To finalize the tests, each individual leaf was manually cut out from the image for each index. The average value calculated was then plotted (Figure 7), further showing the camera's ability to differentiate plant health.

6. Future Work

After such promising results a couple alternatives are made available for future work. Increasing the number of cameras, using specific filters dedicated to an application. An attempt to increase the obtained infrared calculated using the discarded green and blue bands. Remote re-configuration of the camera.

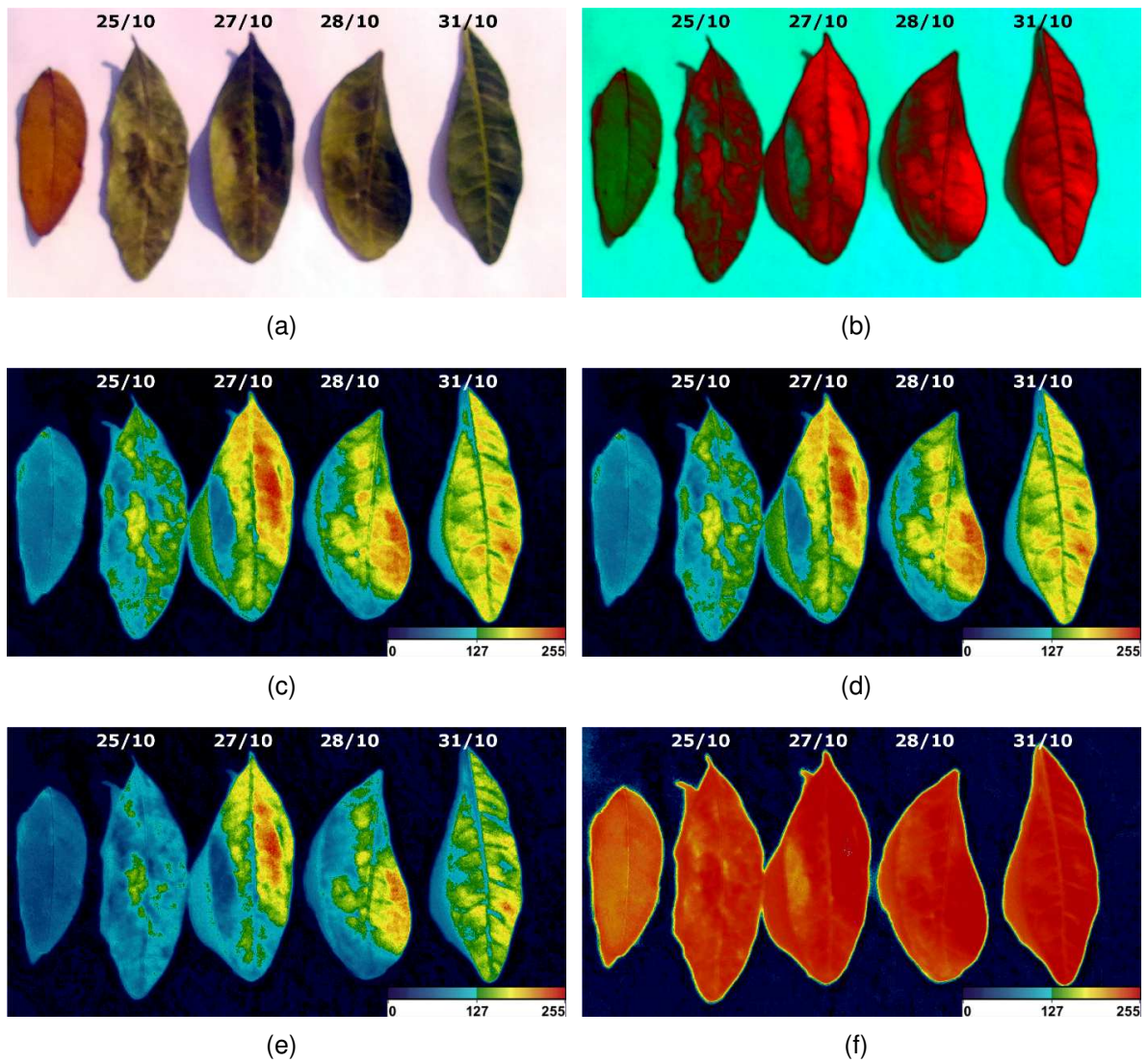


Figure 6: Fine control test: (a) RGB; (b) IR; (c) NDVI; (d) OSAVI; (e) EVI2; (f) MSAVI

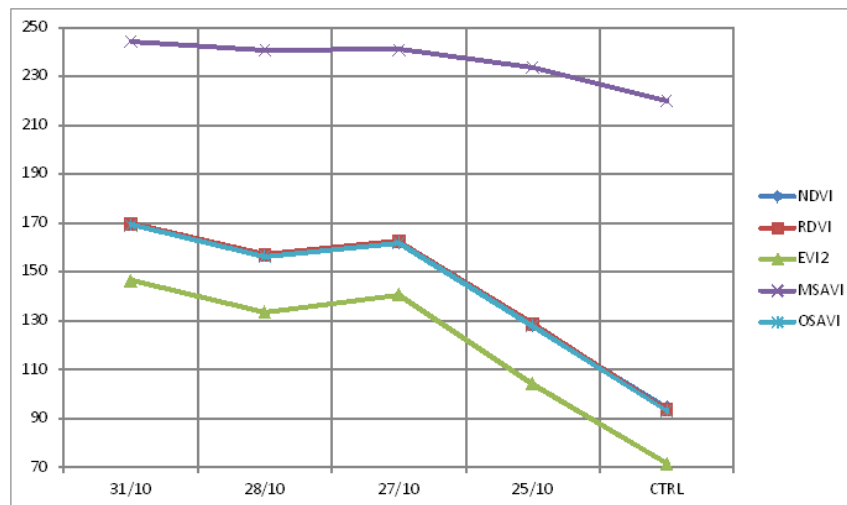


Figure 7: results.

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